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## MEDIUM FREQUENCY PROPAGATION EXPERIMENT AT MISERS BLUFF

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## I INTRODUCTION AND OBJECTIVES

Experiments on the effects of dust clouds on the propagation of electromagnetic waves have been conducted for the last few years at frequencies from 400 MHz upwards.<sup>1\*</sup> There is a military interest in communications at 3 MHz and below through dust clouds. Until the time of experiment, designers of equipment at these frequencies have only speculated on the effects of dust clouds, based on extrapolation from the 400 MHz data and on predictions from scattering theory.

The purpose of the experiment described in this report is to provide experimental data to confirm the prediction that at frequencies below 3 MHz dust would have no appreciable effect on wave propagation. It is hoped that the data will permit a quantitative relationship to be established between dust density, attenuation, phase shift, and (to a lesser extent) the yield of the explosion.

This work was supported by the Defense Nuclear Agency and the U.S. Air Force Space and Missile Systems Organization under contracts DNA001-77-C-0269 and DNA001-79-C-0181. This experiment and results will also be described in Technical Report DNA 4801T-1, which is to be published in the near future.

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\* References are listed at the end of this report.

## II APPROACH TO THE PROBLEM

### A. Experimental Design

The basic configuration of the experiment is shown in Figure 1, with a primary transmission path passing through ground zero (GZ) and a secondary path off at  $90^\circ$  for normalization purposes. We expected to experience some shock effects, and possible damage, at the two close-in sites, which would result in changes in the baseline level at the receivers. Since transmitter changes would also be detected at the secondary receiving site, we expected to be able to calibrate out any such phase and amplitude effects from the primary data. The antennas were vertical monopoles mounted on 8-m telephone poles with the lower 3 m buried. Ground currents were returned through copper screening wound around the buried section; the whole antenna was driven in an unbalanced mode. An antenna loading coil was wound onto the pole immediately above the feed point.

Because of the long wavelengths involved, diffraction effects were a possible source of errors; the antennas were positioned close to the detonation to ensure that the direct path would be completely filled with dust. This led to the question of whether the antennas could survive the blast. Consequently, a second set of buried antennas was installed with a common phase center to the primary antennas. We were, therefore, able to study the relative performance of the buried and exposed antennas during and after the shot.

Buried horizontal dipoles were colocated with each of the telephone pole antennas. The design and anticipated performance of these antennas were taken from studies published by RADC<sup>2</sup> and by the Boeing Corporation<sup>3</sup>. The depth of burial was just sufficient to ensure no damage from the shock wave, and electrically the antennas could be considered to be at the air/soil interface. The purpose of these secondary antennas was twofold: (1) to provide a backup in case the primary antennas

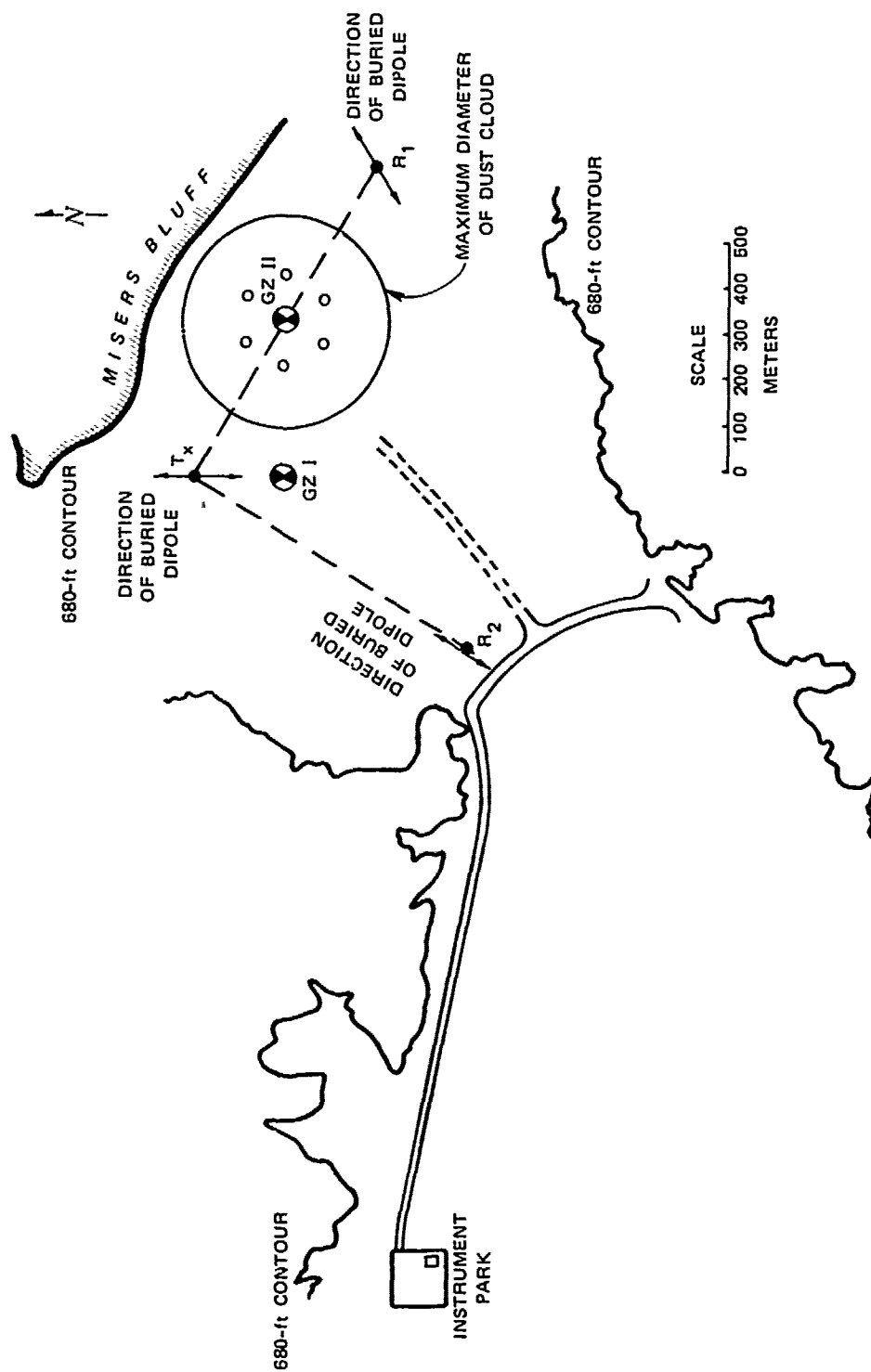


FIGURE 1 EXPERIMENT CONFIGURATION



failed on passage of the shock wave, and '2) to provide a basis for comparing the performance of the two types of antenna under "near miss" conditions.

A number of factors used in the interpretation of any observed effects bothered us in the early stages of experimental design. Our main concern, particularly since we were aiming for a system sensitivity of 0.1 dB and  $1^\circ$  in phase, was to make sure that we had a completely defensible experiment, even in the unlikely event that some major propagation effects were seen. The possibility of multipath propagation interfering with the data was minimized by placing the antennas very close to GZ, so that the dust cloud would completely envelope both the transmitter and the primary receiving sites. The cloud was also expected to fill the area between MISERS BLUFF and GZ, which constituted the most likely source of multipath interference. The antennas were placed 400 m on either side of the GZ on a radial oriented approximately parallel to the bluff. The over-pressure at the points was expected to be 5 psi. This was not our first choice for orientation but was largely dictated by such field considerations as already emplaced cable and other experiments competing for space.

A second source of concern was the length of the cable runs from the antennas to the instrumentation park, where the data analysis equipment was to be located. These cables would carry both the drive signals for the transmitters and the received signals from the antennas, and would be approximately 2500 m in length. We were concerned that if there was a poor ground at the transmitter or a mismatch at the cable ends, we could inadvertently radiate from the 2500-m cable rather than the 5-m vertical monopole. To remove any possibility of this, the cables were terminated 20 m from the antennas, and an optical link carried the signals from this point to and from the antenna amplifiers.

The signals were analyzed for phase shift and attenuation by a series of Hewlett-Packard 8407 Network Analyzers--one for each receiving antenna. The output of these instruments was to be recorded both on tape (Ampex FR 1300) and on paper (Honeywell Visicorder). We also

recorded the voice of Test Control with the countdown timing. The equipment is shown in Figure 2. The left rack contains the above-ground antenna instruments and the Ampex recorder, the right rack contains the subsurface-antenna analysis equipment. The gap in the rack was for the Honeywell Visicorder, which, unfortunately failed 48 hours before the event. Attempts to integrate a substitute recorder (flown in from SRI the evening before the shot) were unsuccessful. This, the only equipment failure during the experiment, resulted in data from the subsurface antenna at the secondary receiving site not being recorded. Since these data would be critical only if the colocated vertical antenna failed, we were not overly concerned. Phase data from both the buried and vertical antennas at the primary site were, therefore, ratioed against the signals from the vertical normalizing antenna.

#### B. Antenna Design

Because we desire to have the primary transmission path filled by the dust cloud, the antennas had to be placed close to GZ. Based on the results of the Phase I detonation, we decided that the transmitter and primary receiver sites should be 400 m on either side of the center of the explosives array. This meant that we could anticipate approximately 5 psi of over-pressure on each antenna. A dynamic analysis was done to predict the flexure and possible permanent deformation (or destruction) of the telephone poles used for the antenna support. The expected deflections are given in Table 1. As a result of the analysis, the 30-cm diameter pole was considered survivable, and was used in the experiment.

The impedance of the vertical antenna was estimated using a ground conductivity value of 10 mmho/m. Attempts to measure the conductivity in the field with standard geophysical equipment failed because of the high electrode resistance in the dry upper dust layers. Simple analyses at SRI indicated that a loading coil of some 40  $\mu$ H would be required for proper loading of the antenna. We planned to operate the antenna in an unbalanced mode, assuming that the buried portion of the pole would act more like a ground plane than a monopole. To aid in the return of ground currents, several hundred gallons of water were poured in the telephone

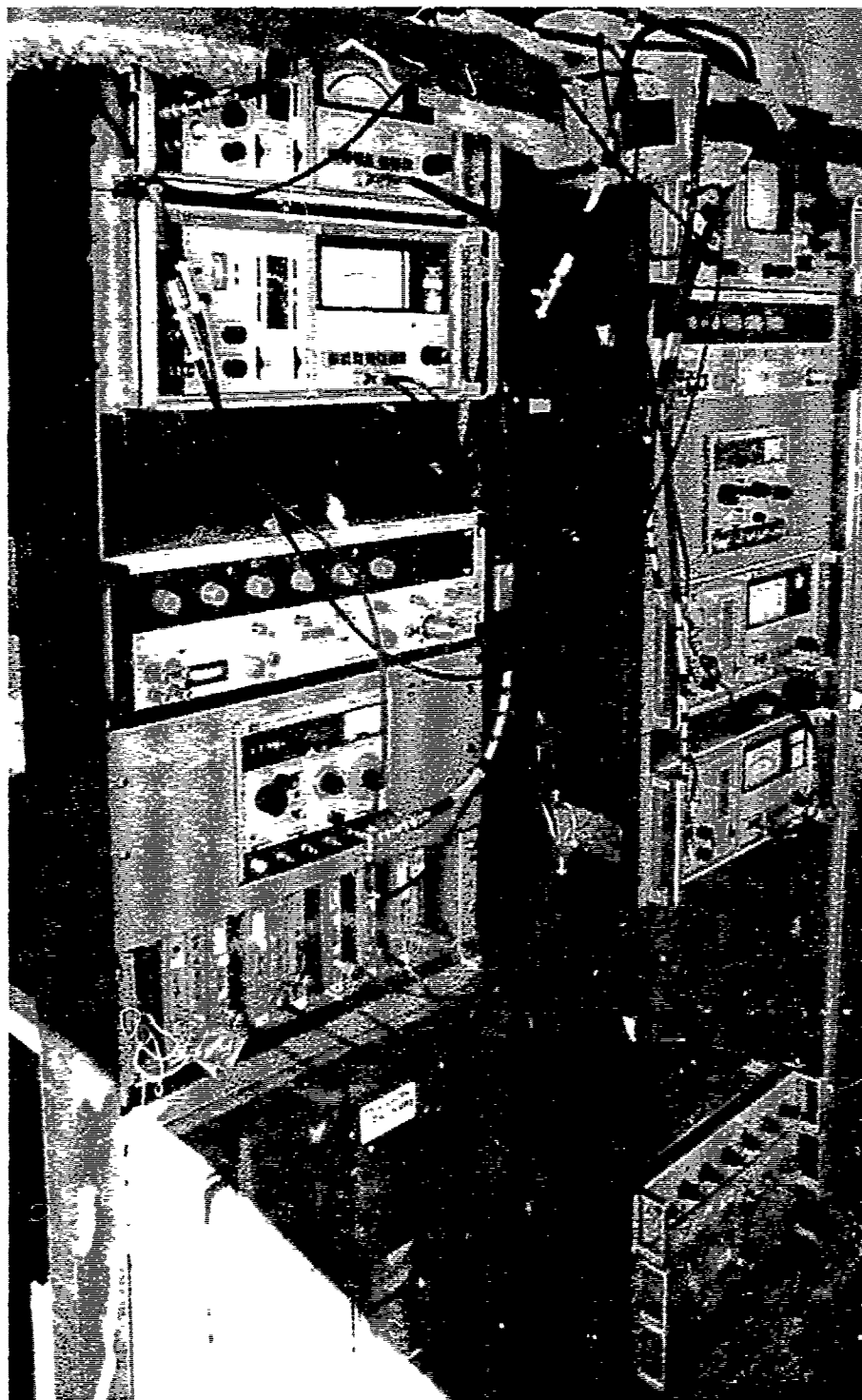


FIGURE 2 ANALYSIS EQUIPMENT IN SHELTER

Table 1  
PREDICTED ANTENNA DEFLECTION AT 5 psi REGION

Pole Diameter	14 cm (5.5 in.)	30 cm (12 in.)
Maximum elastic deflection	36.6 cm	6.6 cm
Permanent deflection	0 cm	2.1 cm

pole during emplacement. This also helped the mechanical stability of the antenna by compacting the fill material. Figure 3 shows the vertical transmitter antenna with the transmitter enclosure still open. During the antenna emplacement, aluminum sheeting was used to sheath the antenna, secured by nails and steel bands. By these means, we both increased the strength of the configuration and made it less vulnerable to major damage by the cutting action of missiles resulting from the explosion.

The subsurface antennas were 6-m horizontal dipoles; the minimum in the antenna pattern was pointed toward MISERS BLUFF to reduce the contribution of reflected energy received. The antennas were fed by a suitable balanced network. The predicted antenna pattern is shown in Figure 4.

### C. Electronics

Figure 5 shows the configuration of the transmitter and receiver electronics, which was identical for both the vertical and subsurface antennas. Both antennas were driven by Class C amplifiers that were left on, but they could be turned into a nonradiating mode during the ANFO arming sequence by removing the transmitter drive at the equipment shelter. In the nondriven condition, battery power consumption was minimal and did not constrain the experiment. The optical links were used to isolate the cables and the antenna electronics, as previously mentioned. Figure 6 shows the vertical antenna at the secondary site before detonation, and Figure 7 the primary receiving station after detonation.



FIGURE 3 TRANSMITTER SITE BEFORE THE SHOT

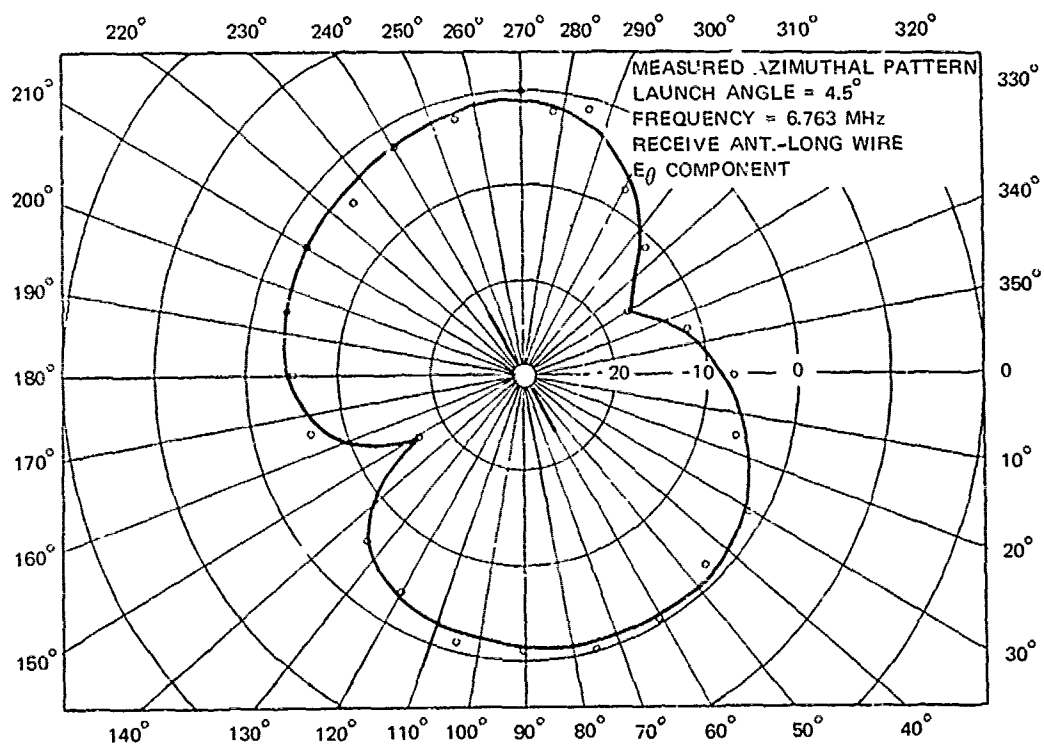


FIGURE 4 AZIMUTHAL PATTERNS OF SUBSURFACE DIPOLES  
 (AFTER ENTZMINGER)

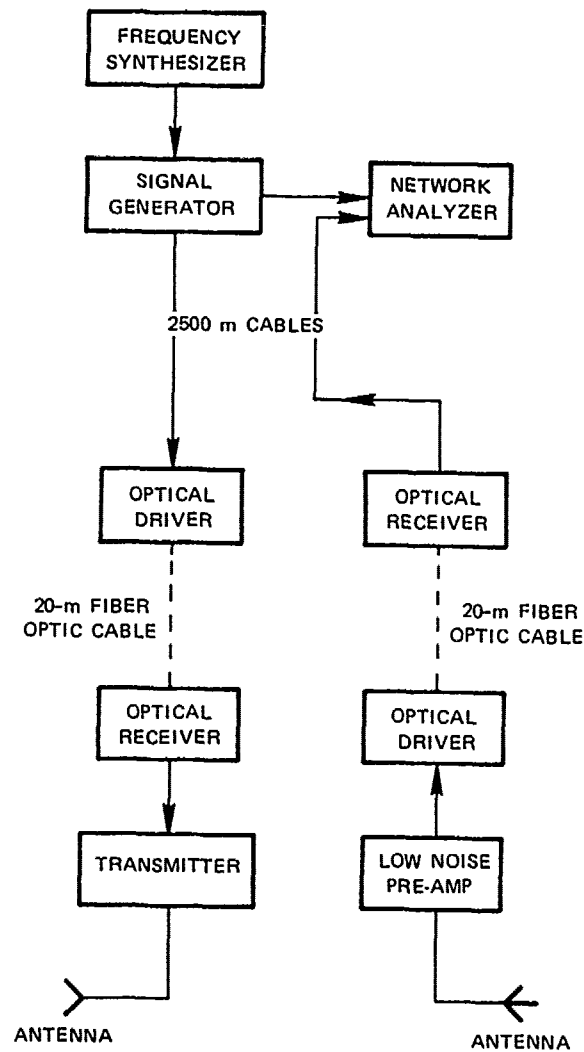


FIGURE 5 EQUIPMENT BLOCK DIAGRAM

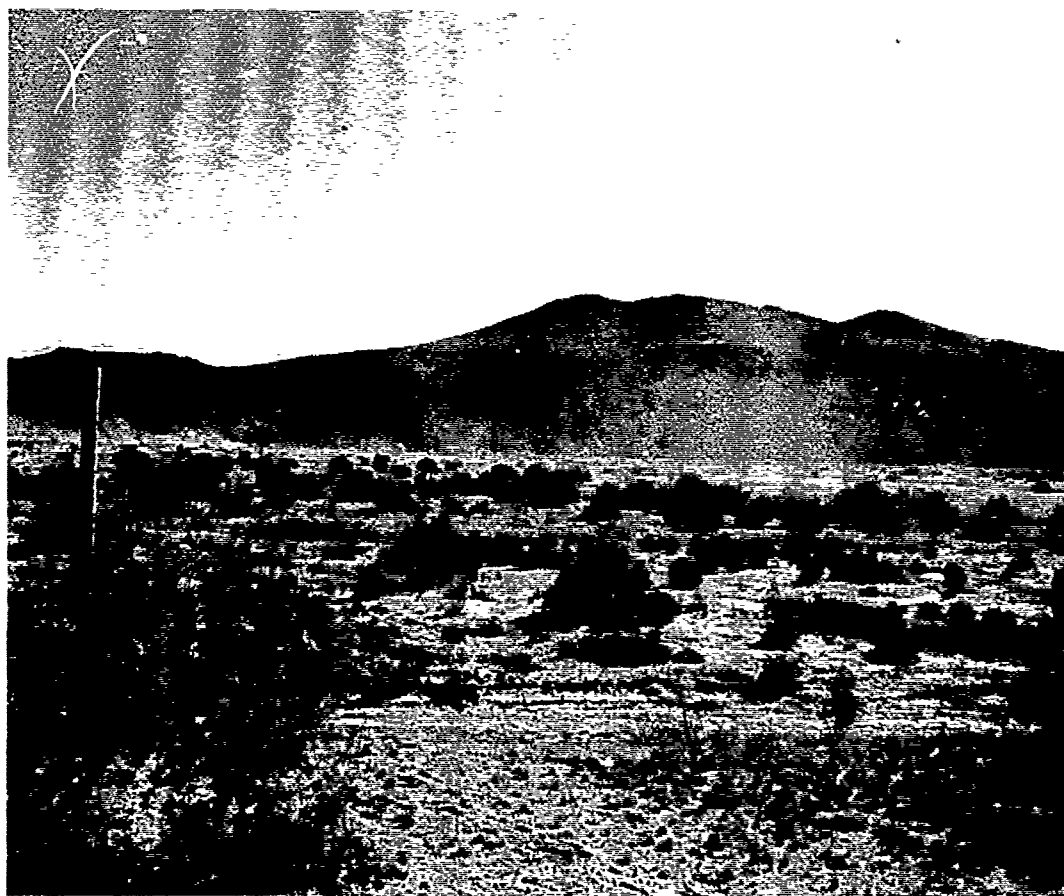


FIGURE 6 SECONDARY RECEIVER SITE



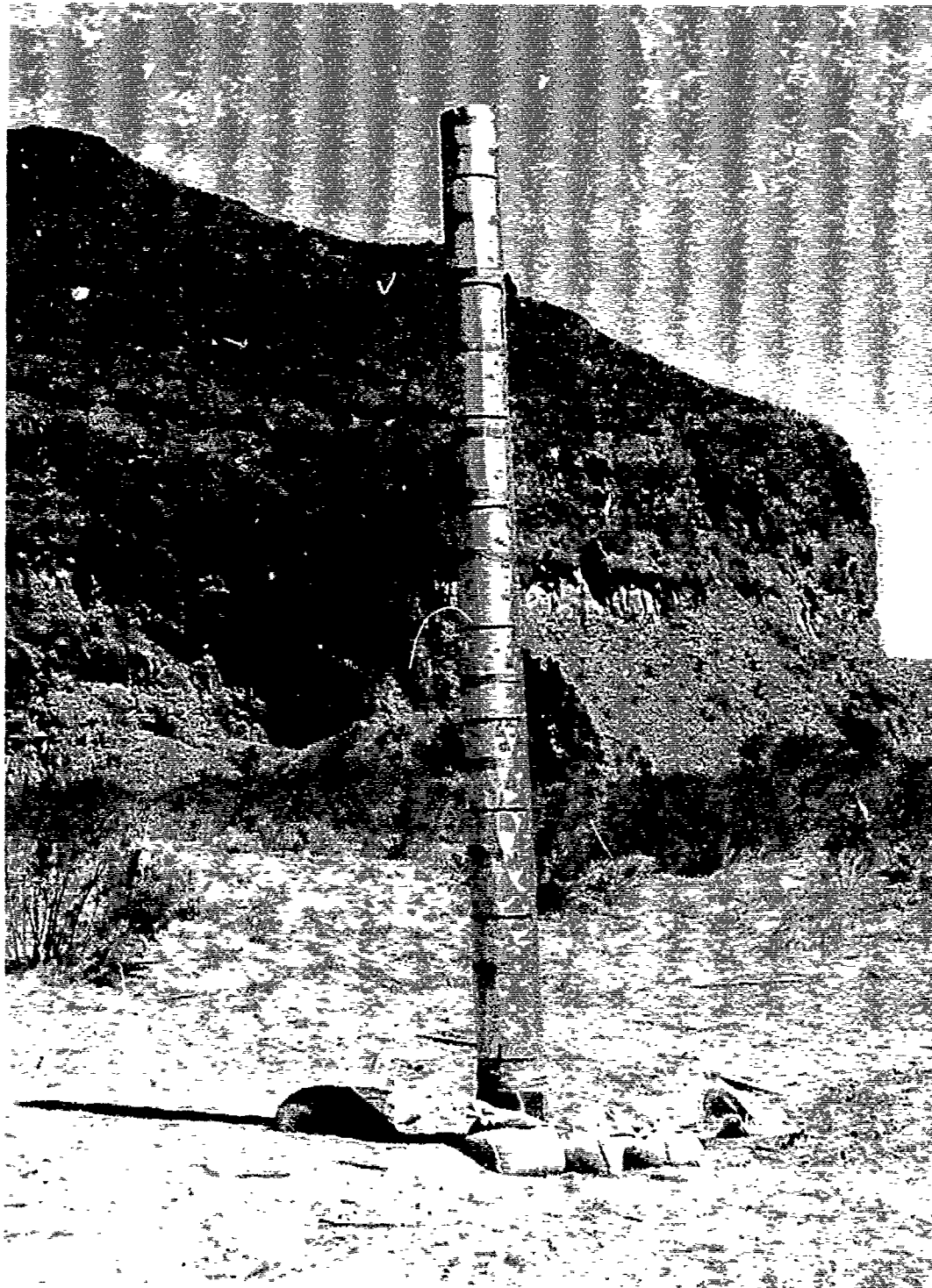


FIGURE 7 PRIMARY RECEIVING SITE

For the day of the shot, the shelter was tied down, all circuit breakers were hard wired "on" and all windows were boarded over, since we were uncertain of the pressure levels to be expected at this site. The site was manned during the shot.

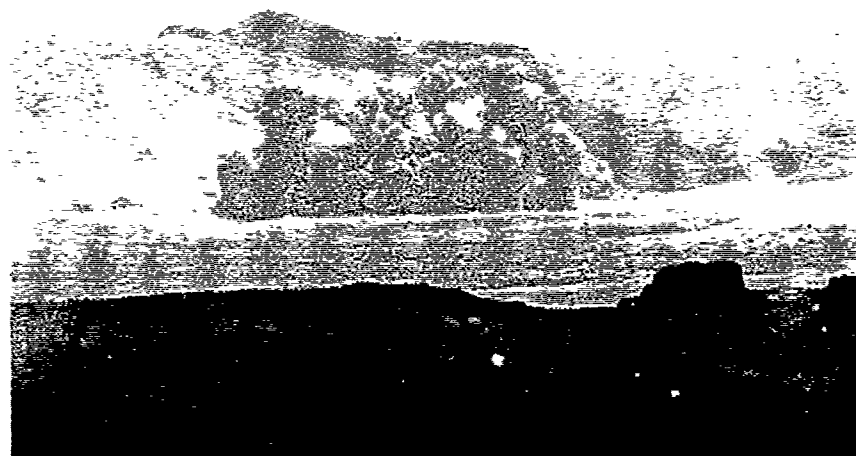
### III THE EVENT

During preparations on the day of the shot, we were hampered somewhat by unexpected restrictions on vehicle movement during the early hours of the morning ( $T - 4$  hours). This prevented us from adequately checking the repairs on our primary receiving cables, which had been cut the day before. Fortunately, the repairs were good, and after turning all the equipment on, we had signals to and from all antennas at the equipment shelter. The countdown went normally, with a 45 min hold for weather. We began recording data at  $T - 15$  min to establish any drift as the valley heated up after sunrise. Data recording continued through the shot until  $T + 30$  min. Figures 8 and 9 show the dust cloud at various stages of development, viewed from 10 miles away; Figure 10 shows it as seen from the equipment shelter at approximately  $T + 30$  s.

Apart from the high noise level, no adverse effects were noted as the shock wave passed through the equipment shelter. We did not see any loss of phase lock at any time on any of the recorded channels. After the shock wave passed, the amplitude of the vertical antenna signal at the primary site dropped approximately 10 dB and stayed there. Subsequent inspection showed no apparent damage, and the only expected change in performance was due to the 2.1 cm permanent deflection mentioned earlier. Since the other antennas provided normalizing signals, the 10 dB drop simply represented a shift in baseline.



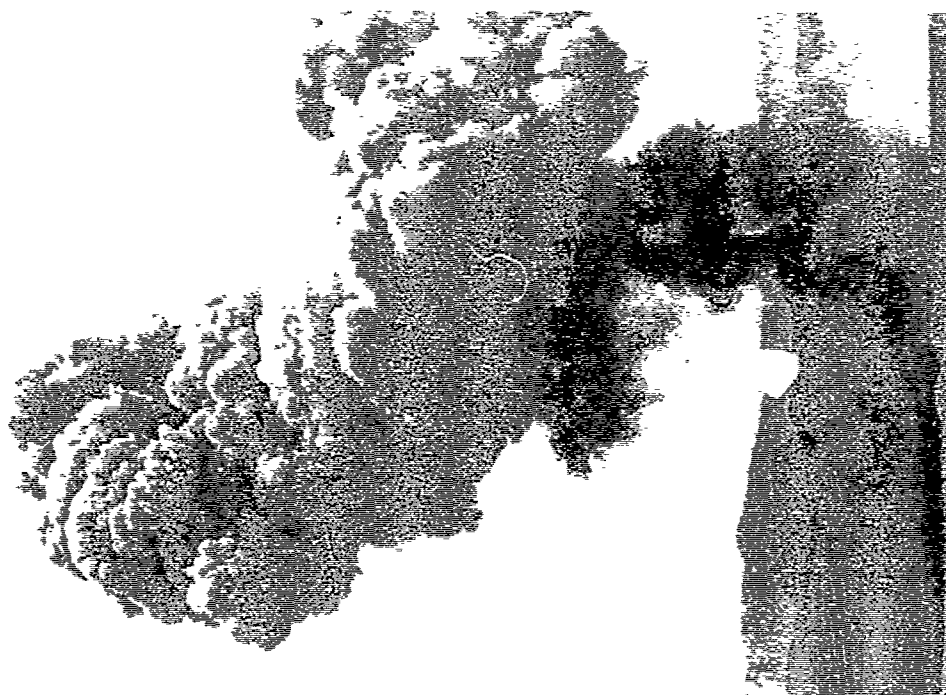
T + 6 sec



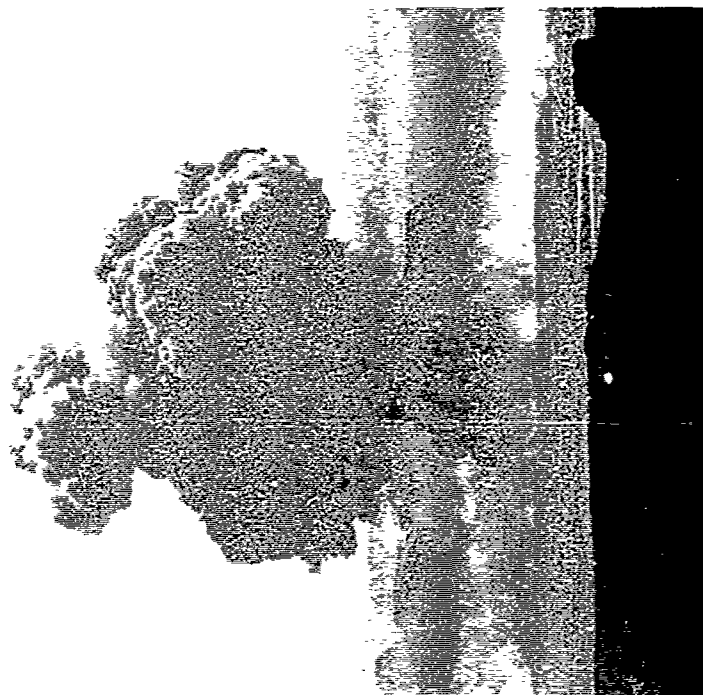
T + 11 sec

(Courtesy of W. G. Chesnut)

FIGURE 8 MISERS BLUFF II DETONATION



(Courtesy of W. G. Chesnut) T + 2 min



T + 1 min

FIGURE 9 MISERS BLUFF II DETONATION



FIGURE 10 DUST CLOUD VIEWED FROM EQUIPMENT SHELTER

#### IV DATA REDUCTION AND RESULTS

Reduction of the MF data has included stripping out the data and calibrations on paper, and plotting the amplitude and phase deviations as a function of time. No reliable data on the dust density of the cloud are now available. Therefore, a first-order estimate has been made using the observed size of the craters and the photographs of the cloud size. No attempt has been made to analyze the first 3 s or so of data because of time and cost constraints, and because of the difficulty in separating real propagation effects from those due to antenna motion.

Figure 11 shows a section of the output from the phase channels from the vertical antennas as a function of time. The detonation time and blast effects are clearly seen. The impact of the shock waves on the equipment shelter is seen at the  $T + 5$  s. Both channels eventually return to a new baseline, which means that the shock wave caused individual permanent changes to each of the two close-in antennas. Because of the greatly increased distance to the second receiver site, we are assuming that any change in antenna performance at this second site is minimal compared with that of the two close-in antennas. Table 2 shows the differential phase shift between the two receivers as a function of time for the first 25 s. The phase information used in deriving this table was with reference to the post-shock baseline value. The records before the detonation show that the short-term drift in phase was not sufficient to be of concern. After the shot, however, both receivers showed a phase drift for about 15 min. During this period, the two vertical and the primary buried receiving antennas tracked perfectly in phase, indicating that the drift originated in the transmitter/antenna site; thus it was easy to calibrate out of the data.

The amplitude records show no measurable attenuation of the signal in either the vertical or the horizontal (buried) antenna channels. This important result confirms what had been previously only been assumed by

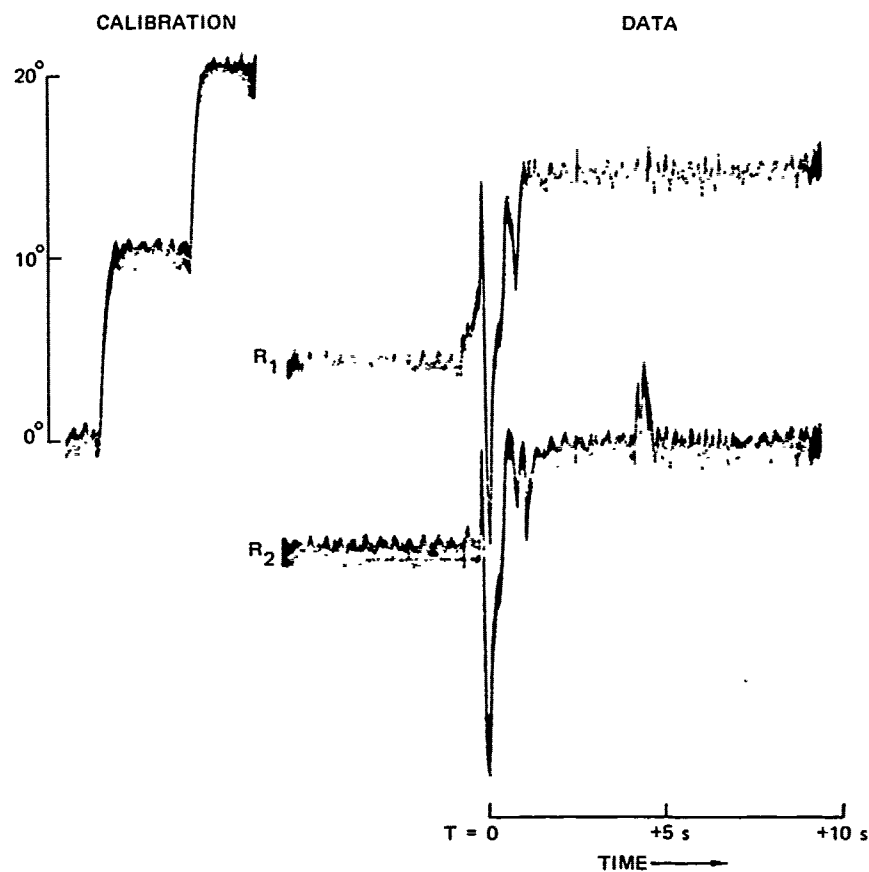


FIGURE 11 RELATIVE PHASE DATA (unsmoothed) FROM VERTICAL ANTENNAS

Table 2

DIFFERENTIAL PHASE SHIFT BETWEEN PRIMARY  
AND SECONDARY PATHS

Time (seconds)	$\delta\phi$ (degrees)
$T + 5$	0.1
$T + 10$	0.2
$T + 15$	0.3
$T + 20$	0.1
$T + 25$	0.0



extrapolating from much higher frequencies. With smoothing, the data were readable to 0.1 dB, and no noticeable deviation was observed. The phase data showed a maximum departure of 0.3°.

The phase shift due to the dust cloud can be crudely calculated from measurements of the crater volume if we assume that for typical alluvium, such as that found in the area around GZ, the dielectric constant,  $E_r$ , is 6 and the soil density,  $\rho$ , is 2 g/cc. We were given,<sup>4</sup> that the six crater volumes were

75,000 ft<sup>3</sup>  
 55,000 ft<sup>3</sup>  
 45,000 ft<sup>3</sup>  
 38,000 ft<sup>3</sup>  
 66,000 ft<sup>3</sup>  
 80,000 ft<sup>3</sup>.

The total volume, therefore, was 359,000 ft<sup>3</sup>. Assuming that approximately 50% of this was lofted by the explosion, the mass lofted was:

$$m = 1/2 \times 359,000 \times 28.3 \times 2 \text{ kg} \div 10^7 \text{ kg}$$

Similar estimates, given at a recent symposium on the preliminary findings at MISERS BLUFF,<sup>5</sup> ranged from 1 to 5 x 10<sup>6</sup> kg.

Sequential photographs of the dust cloud during its development were taken from a distant site, as shown in Figures 7 and 8. From photographs in this series it can be calculated that the cloud reached a maximum diameter of a little over 600 m at ground level at around T + 10 s.

Thus, if we assume uniform distribution of the lofted mass, the density  $\rho_c$  is given by

$$\rho_c = \frac{M}{V} \frac{10^7}{1/2 \times 4/3 \pi (300)^3} \text{ kg/m}^3 \div 0.18 \text{ kg/m}^3,$$

or 180 g/m<sup>3</sup>. Therefore, with the assumptions mentioned and a total mass of lofted material somewhere between 10<sup>6</sup> and 10<sup>7</sup> kg, the average density

ranges from 18 to 180 g/m<sup>3</sup>. The phase shift that this should produce is given by

$$\delta\varphi = \frac{2\pi}{\lambda} \cdot \frac{3}{2} \cdot \frac{\frac{E_r - 1}{E_r + 2}}{\rho_d} \int S \rho_c ds ,$$

where

$\delta\varphi$  = Phase shift

$E_r$  = Relative permittivity

$\rho_d$  = Specific gravity of the alluvium

$S$  = Distance through the cloud

$\rho_c$  = Density of the cloud.

Putting the following values:

$$S = 600 \text{ m}$$

$$\lambda = 100 \text{ m}$$

$$E_r = 6$$

$$\rho_c = 180 \text{ g/m}^3$$

$$\rho_d = 2$$

in the equation, we get  $\delta\varphi = 3.1 \times 10^{-3}$  radians, or 0.18° at 3 MHz. The observed values of 0.3° (max) at T + 15 s are therefore reasonable.

The phase records can be read individually to about  $\pm 0.1^\circ$  if they are smoothed. Since the phase deviation is the result of operating on four such readings, the random errors must be at least  $\pm 0.2$ . Other, lesser errors are due to the tape recording process and to amplification and processing before tape recording. Thus we cannot relate cloud density to observed phase shift with confidence, since the total shift is only slightly greater than the error bars.

## V DISCUSSION AND CONCLUSION

The experiment to confirm theoretical predictions on the effects of dust clouds on MF propagation was successfully concluded. The present estimates are that between one and five million kilograms of alluvium were lofted into the air by the Phase II explosion. The electrical properties of the near surface materials indicate that its conductivity, even in bulk form, was very low; therefore one would expect little attenuation at 3 MHz. The only cloud-induced effects noted were in phase, and the maximum phase shift measured corresponds to a dust density of  $300 \text{ g/m}^3$ . These observations are in accordance with expectation. The essentially zero imaginary component of the dust permittivity should cause no absorption effects, and the losses from scattering processes at 100 m wavelengths should also be close to zero. It should be borne in mind that the detonation was only equivalent to half a kiloton of TNT. If one were to scale this up to a megaton or more, the dust effects could be much more serious and long-lived.

Although we have not spent much effort analyzing the first 3 s of data, deviations of  $10^\circ$  or more in phase and 3 dB in amplitude did occur in this time period. The major results of the experiment are as follows.

### A. Questions That Have Been Answered

The measured attenuation was less than 0.1 dB at 3 MHz after  $T + 3 \text{ s}$ . The phase maximum shift was  $0.3^\circ$  at approximately 15 s, compared with the calculated value of  $0.18^\circ$  assuming a cloud density of  $180 \text{ g/m}^3$ . The experiment thus succeeded in its first objective, which was to verify that dust clouds from small detonations, such as MISERS BLUFF, have little effect on propagation at 3 MHz.

4  
B. Questions That Remain

The passage of the shock wave caused large and permanent performance variations in the vertical antennas and, to a lesser extent, in the buried primary receiver antenna. We feel that it is important to extrapolate the effects of the 0.5 kT blast to larger yields (MT or more) to eliminate the possible ground motion effects on buried antennas. These effects can be estimated by a mixture of analytical procedures and experimental data from larger detonations (possibly below-ground nuclear events).

The passage of the shock wave caused phase and amplitude excursions of over  $10^\circ$  and 3 dB which lasted about 3 s. Again, how does this scale to larger blasts? If the period during which the phase and amplitude were experiencing perturbations, due to ground motion and shock effects, were to increase to tens of seconds or even more, then the confidence level of communications links operating with buried antennas is reduced. Once the effects are characterized, it should be possible to devise signal handling schemes that would process out such variations.

In summary, we observed some relatively minor effects from a 0.5 kT detonation in Arizona. These effects may give rise to important system reliability questions when (a) scaled up to larger explosions, and (b) situated in different soils, temperature and humidity conditions, as in North Dakota. It is equally possible that with the current design of communication systems for use in silo communications, the shock and ground motion effects will not be critical. To resolve this ambiguity one would have to look at the design of the antennas, the anticipated ground motion at a variety of locations, and the sensitivity of the signals being transmitted to phase and amplitude noise. One logical way of answering many of these questions would be to take a series of antennas manufactured to the current design, subject them to shock, and monitor the response function using signal frequencies close to those used in actual operation.

This would answer the ground motion questions. The effects of larger dust clouds would have to be derived by extrapolating from the MISERS BLUFF data.

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